METHOD AND SYSTEM FOR BENEFICIATING GASIFICATION SLAG

BACKGROUND OF THE INVENTION

Field of the Invention

The present invention relates generally to the gasification of coal and similar carbonaceous solids and, more particularly, to methods and apparatus for beneficiating the resulting gasification slag.

Description of Related Art

Coal and other carbonaceous solids are commonly used as fuel in electricity generating processes. For example, in a fluidized bed process, also referred to as gasification, carbonaceous solids (*i.e.*, coal, char, etc.) are thermally converted into a combustible gaseous product via partial oxidation in a reactive gaseous atmosphere. The product of gasification is a reactive gas composed of carbon monoxide and hydrogen. This gas can be used as a fuel directly or it can be converted to other products such as synthetic oil. The inorganic portion of the coal forms a vitreous slag by-product.

Referring to Figure 1, there is illustrated a process flow diagram for one embodiment of a gasification facility, such as the Polk Station operated by Tampa Electric Company in Mulberry, Florida. Feed coal is ground and mixed with water at a slurry plant **10** to produce a slurry containing approximately 60-70% solids. The coal slurry is fed into the top of an entrained-flow gasifier **12** along with oxygen from an oxygen plant **14** to produce a high temperature, high pressure, medium Btu synthesis gas of approximately 267 Btu/scf. The synthesis gas is cooled in one or more heat exchangers **16** to generate high-pressure steam that can be used to power a steam turbine **20** to generate electricity. The cooled synthesis gas is cleaned in a scrubber **22a** and particulate filter **22b** to remove contaminants such as sulfur and ash and then combusted along with nitrogen (N_2) in a gas turbine **24** to generate electricity.

Coal gasification differs significantly from combustion, which is a more widely applied coal utilization technology. During combustion, coal is burned to produce heat and fully oxidized combustion gases, primarily carbon dioxide and water vapor. The

inorganic portion of the coal forms "fly ash" a very fine dry powdery material that is typically collected dry in cyclones, electrostatic precipitators and baghouses. A much smaller amount of ash also is collected from the combustor as coarser "bottom ash." Bottom ash particles are irregularly-shaped, frequently porous and low in carbon content.

Not surprisingly, the nature of the by-products generated by gasification and combustion is as different as the technologies are. Slag, which is the by-product of gasification, comprises molten or partially fused particles that come into contact with the furnace wall, become chilled, and solidify. Typically, slag is removed from the gasifier as a slurry. Slag is generally much denser than either fly ash or bottom ash. The coarse component of the slag is essentially a coarse vitreous, high density, abrasive solid that is low in carbon content. The physical shape of the coarse slag particles ranges from rod or needle-like structures to irregular-shaped jagged pieces. The finer slag is comprised of char or unburned carbon particles containing varying amounts of siliceous ash. The carbonaceous phase of the ash is irregularly shaped particles with a highly developed pore structure.

Slag is generally not usable when it comprises a mixture of coarse, vitreous material and fine, porous carbon material, such as when the slag is removed from the gasifier. Accordingly, there is a need for methods and apparatus to beneficiate the slag by-product into its coarser and finer constituents. The method and apparatus should enable not only the economical separation of the slag by-products into useful components, but the separation of the by-products into useful components with acceptable quality and sizing for specific end use markets.

SUMMARY OF THE INVENTION

The present invention provides apparatus and methods for beneficiating slag economically. According to one embodiment, the method includes mixing the slag with water to form a slurry. The mixing step can include agitating the slag to break up any agglomerated particles. The slurry is screened through a first screen to remove a first portion of material and then screened through a second screen to remove a second portion of material. A fluid can be sprayed onto one or both of the first and second screens

concurrently with the corresponding first and second screening steps to facilitate the passage of material through the screens. The first and/or second screens can also be vibrated concurrently with the corresponding first and second screening steps to facilitate the passage of material through the screens.

In one embodiment, the second portion of material has a carbon content less than about 5% and, more preferably, a carbon content less than about 1%. Although the size of the particles in the first and second portions can vary, in one embodiment the first portion of material has a particle size exceeding approximately .5 inches. In another embodiment, the second portion of material has a particle size of between approximately .5 inches and approximately 840 μm.

According to another embodiment of the present invention, the method includes screening the slurry subsequent to the second screening step through a centrifuge to remove a third portion of material. The third portion of material preferably has a higher carbon content than the second portion of material. The size of the particles in the third portion can vary. In one embodiment, the third portion of material has a particle size between approximately 840 μm and approximately 45 μm. The third portion of material preferably has a higher carbon content than the second portion of material. The third portion of material can be used as a fuel product or adsorbent carbon. In still another embodiment, the slurry is thickened subsequent to the third screening step using an anionic flocculant such as polyacrylamide or acrylamide copolymers to thereby remove a fourth portion of material from the slurry. If desired, a pH modifier such as sodium hydroxide or ammonium hydroxide can be used to clarify the water. The fourth portion of material can thereafter be processed using a belt filtering press to dewater the fourth portion of material. The processed fourth portion of material can be used as a fuel product or adsorbent carbon.

According to yet another embodiment of the present invention, the method includes screening the slurry subsequent to the second screening step using a hydrocyclone to remove a third portion of material. The third portion of material preferably has a higher carbon content than the second portion of material. The size of the particles in the third portion can vary. In one embodiment, the third portion of

material has a particle size of between approximately 840 μm to approximately 75 μm. The third portion of material or "underflow" from the hydrocyclone preferably is dewatered using a centrifuge. The third portion of material can be used as an adsorbent carbon or a fuel product. Subsequent to the third screening step, the slurry can be further processed by thickening the slurry using an anionic flocculant such as polyacrylamide or acrylamide copolymers to thereby remove a fourth portion of material from the slurry. If desired, a pH modifier such as sodium hydroxide or ammonium hydroxide can be used to clarify the water. Thereafter, the fourth portion of material can be processed using a belt filtering press to dewater the fourth portion of material. In one embodiment, the fourth portion of material has a particle size of less than approximately 75 μm. The fourth portion of material can be used as a fuel product or adsorbent carbon.

The present invention also provides a system for beneficiating a slag slurry into usable portions. According to one embodiment, the system includes a first screen for removing a first portion of material from the slurry. The system also includes a second screen for removing a second portion of material from the slurry. In one embodiment, the second portion of material has a carbon content of less than about 5% and, more preferably, less than about 1%. Although the size of the particles in the first and second portions can vary, in one embodiment the first portion of material has a particle size exceeding approximately .5 inches. In another embodiment, the second portion of material has a particle size of between approximately .5 inches and approximately 840 μm. In one embodiment, the system includes a blunger for mixing and agitating the slurry. In another embodiment, the system includes at least one sprayer for spraying fluid onto at least one of the first and second screens to facilitate the passage of material through the screens. In still another embodiment, the system includes at least one vibrator for vibrating at least one of the first and second screens to facilitate the passage of material through the screens.

According to another embodiment of the present invention, the system includes a centrifuge for removing a third portion of material from the slurry. The third portion of material preferably has a higher carbon content than the second portion of material. While the size of the particles in the third portion can vary, in one embodiment the third

portion of material has a particle size of between approximately 840 μm and approximately 45 μm. The system can further include a thickener for removing a fourth portion of material from the slurry. In one embodiment, the system includes a belt filtering press for dewatering the fourth portion of material.

According to yet another embodiment of the present invention, the system includes a hydrocyclone for removing a third portion of material from the slurry. The third portion of material preferably has a higher carbon content than the second portion of material. While the size of the particles in the third portion can vary, in one embodiment the third portion of material has a particle size of between approximately 840 μm and approximately 75 μm. The system can include a centrifuge for dewatering the third portion of material. The system can further include a thickener for removing a fourth portion of material from the slurry. In one embodiment, the system includes a belt filtering press for dewatering the fourth portion of material.

Accordingly, there has been provided methods and apparatus to beneficiate the slag by-product from gasification economically. The methods and apparatus enable not only the separation of the slag by-products into useful components, but also the separation of the by-products into useful components with acceptable quality and sizing for specific end use markets. The coarse slag by-product, which preferably includes the first and/or second portions of the material, has unique physical and chemical properties and can be used for many applications, including abrasive media (*i.e.*, sand blasting grit), polishing media, roofing granules, cement kiln feed, athletic track surfaces, landscaping, and road surface coatings. In addition, the coarse slag by-product can also be milled and used as a pozzolanic cement additive to improve the properties of concrete. The finer slag by-product, which preferably includes the third and fourth portions of the material, can be utilized as a supplemental pulverized coal combustion fuel and has shown excellent potential as both an adsorbent and as a precursor for activated carbon.

BRIEF DESCRIPTION OF THE DRAWINGS

The foregoing and other advantages and features of the invention, and the manner in which the same are accomplished, will become more readily apparent upon

consideration of the following detail description of the invention taken in conjunction with the accompanying drawings, which illustrate preferred and exemplary embodiments and which are not necessarily drawn to scale, wherein:

Figure 1 is a diagram illustrating a coal gasification process, as is known in the art;

Figure 2 is a flow diagram illustrating an apparatus for beneficiating slag by-product, according to one embodiment of the present invention;

Figure 3 is a flow diagram illustrating an apparatus for beneficiating slag by-product, according to another embodiment of the present invention;

Figure 4 is a table illustrating the size analysis of a composite feed sample, according to one embodiment of the present invention;

Figure 5 is a table illustrating a condensed size distribution, once oversize material is removed and selected size fractions are combined, according to one embodiment of the present invention;

Figure 6 is a table illustrating the size analysis of a second portion of material beneficiated according to one embodiment of the present invention;

Figure 7 is a table illustrating the size analysis of a third portion of material beneficiated using the system illustrated in Figure 2;

Figure 8 is a table illustrating the size analysis of a third portion of material beneficiated using the system illustrated in Figure 3;

Figure 9 is a block diagram illustrating a method for beneficiating slag by-product, according to one embodiment of the present invention; and

Figure 10 is a block diagram illustrating a method for beneficiating slag by-product, according to another embodiment of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

The present invention now will be described more fully hereinafter with reference to the accompanying drawings, in which some, but not all embodiments of the invention are shown. This invention may be embodied in many different forms and should not be construed as limited to the embodiments set forth herein; rather, these embodiments are

provided so that this disclosure will be thorough and complete, and will fully convey the scope of the invention to those skilled in the art. Like numbers refer to like elements throughout.

Referring to Figure 2, there is illustrated a diagram of a slag beneficiation system or apparatus **26**, according to one embodiment of the present invention. According to the illustrated embodiment, the apparatus **26** includes a blunger **28**, slag sizing screens **30**, a centrifuge **34**, a thickener **36** and a belt filter press **38**. The blunger **28** comprises a tank or other holding vessel **28a** structured to receive water and slag and a mechanical agitator **28b** having a paddle, impeller or other mixing tool **28c** rotatably attached to a motor **28d** for mixing or stirring the water and slag into a slurry. For example, in one embodiment, the blunger **28** comprises an 8 ft. by 8ft. tank **28a** with a 10 hp motor **28d** and a four (4) blade mixing tool **28c**, such as is the Svedala brand of blunger distributed by Metso Minerals.

The slurry is pumped to the sizing screens **30** from the blunger **28** using pump **42**. The slag sizing screens **30** preferably include at least two screens **30a**, **b**, which can be arranged in series with appropriate piping or channeling (not shown) provided to move the slurry between the screens. The number of screens can vary from two to three or more screens depending on the number of portions into which the slag is to be separated. In another embodiment, the sizing screens are mounted together in a screen deck **32** in which the sizing screens are superimposed in descending order of sizing, *i.e.*, the screen with the largest sizing is first and the screen with the smallest sizing is last. For example, as illustrated in Figure 2, the first screen **30a** is superimposed over the second screen **30b** and so forth as part of a screen deck **32**. The screen deck **32** preferably includes a vibrator **33**, such as a motor or other oscillating device, structured to vibrate at least one of the sizing screens **30** and, preferably, each of the screens. In embodiments where the sizing screens are in series (not shown), each screen can have a vibrator **33** attached thereto. The sizing of the screens **30** can vary depending upon the specifications of the portions to be beneficiated from the slag. According to one embodiment, the first screen is a .5 inch (12.7 mm) screen **30a** and the second screen **30b** is a 20 mesh (841 μm) screen. The system preferably includes one or more spray bars or nozzles **35** structured

and positioned to direct fluid, such as a liquid or gas, against the screens to ensure that all of the material having a size less than the sizing of the corresponding screen passes through the screen.

The centrifuge **34** comprises a conical drum or bowl that rotates between approximately 2000 to 4000 rpm. The slurry can be pumped to the centrifuge **34** from the sizing screens **30** using pump **52**. The slurry is fed into one end and the separated solids are moved up the bowl by a rotating scroll to exit at the other end, as is known in the art. For example, the centrifuge **34** can comprise a 44 inch by 132 inch horizontal screen bowl dryer with a 400hp motor, as is distributed by Decanter Machine, Inc.

The thickener **36** comprises a tank or other holding vessel **36a** structured to receive a slurry of water and slag. For example, the slurry can be pumped to the thickener **36** from the centrifuge **34** using pump **64**. The thickener **36** preferably comprises a static thickener using anionic flocculants such as polyacrylamide or acrylamide copolymers, which causes the solids in the slurry to settle from the water at a settling rate of approximately 6 inches to approximately 12 inches per minute. A pH control, such as sodium hydroxide or ammonium hydroxide, can be used to obtain acceptable water clarity. According to one embodiment, the thickener **36** comprises a HF- 30F thickener distributed by Phoenix Processing Equipment Co.

The belt filter press **38** comprises a filter medium **38a** attached to a belt **38b**, both of which are in operable communication with a motor **38c**. The filter medium **38a** is structured to dewater the slurry and separate the remaining solids therefrom as the motor **38c** circulates the belt **38b** and filter medium. The sizing and dimensions of the filter medium **38c** will depend upon the specifications for the solids to be dewatered. According to one embodiment, the belt filter press **38** comprises a WX – 3.0 G belt filter press distributed by Phoenix Processing Equipment Co.

According to another embodiment of the invention, as illustrated in Figure 3, the system **76** includes a blunger **88**, slag sizing screens **90**, a hydrocyclone **91**, a centrifuge **94**, a thickener **96** and a belt filter press **98**. The blunger **88** and slag sizing screens **90** operate as discussed above with the slurry being pumped from the blunger to the sizing screens using pump **102**. The hydrocyclone **91** comprises an inverted cone in which the

slurry is fed tangentially into the upper part of the cone. For example, the slurry can be pumped to the hydrocyclone **91** from the sizing screens **90** using pump **112**. The hydrocyclone **91** rotates due to the pressure and velocity of the slurry entering the cone. As the hydrocyclone **91** spins the separated solids or "underflow" are forced against the wall of the cone and out the apex of the cone. The spinning motion results in the water in the slurry exiting out the top of the cone, which is referred to as the "overflow." According to one embodiment, the hydrocyclone **40** comprises a 15-inch cyclone distributed by Krebs Engineers.

The overflow from the hydrocyclone **91** can be pumped using pump **122** to the thickener **96**. The underflow from the hydrocyclone **91** can be pumped using pump **132** to the centrifuge **94**. Alternatively, the underflow is fed from the hydrocyclone **91** to the centrifuge **94** via gravity feed. The centrifuge **94** operates to dewater the underflow from the hydrocyclone **91**. Any remaining slurry from the centrifuge **94** can then be pumped using pump **142** to the thickener **96** along with the overflow from the hydrocyclone **91**. The thickener **96** operates, as discussed above, to settle solids from the slurry. The separated solids from the thickener **96** can be pumped using pump **144** to the belt filter press **98**, which operates as discussed above to dewater the solids.

During operation of the system **26**, the first step in slag beneficiation is typically to produce a pumpable slurry from the slag to be processed. Referring to Figure 1, since the slag typically is removed from the gasifier **12** as a slurry, it would be technically feasible to pump the slag directly from the gasifier to the processing system **26**. While this approach is technically feasible, it would require that the processing system be operated whenever slag is produced. In addition, the slag processing system **26** would need to match the slag generating capacity of the gasifier **12**, or provide surge storage.

According to another embodiment of the present invention, the slag preferably is removed from the gasifier **12** as a slurry, dewatered and stored in a stockpile (not shown). Thereafter, stored ash is retrieved and mixed with water or "re-slurried" at a rate to match the operating capacity of the beneficiation system **26**. For example, in the embodiments illustrated in Figures 2 and 3, the slurry is produced by metering the stored slag with recycled plant process water and water from the beneficiation system **26**, **76** into the mix

tank **28a, 88a** of the blunger **28, 88** where the water and slag are mixed and agitated into a slurry. The consistent operation of this feed preparation stage is important for effective beneficiation of the slag for two primary reasons. First, the feed preparation stage provides a uniform feed or slurry to the sizing screens **30, 90** and breaks apart agglomerated particles. This is particularly important in slag processing because the slag is quite dense and settles readily. Since approximately 30% of the feed slurry solids will be retained on the sizing screens **30**, it is imperative that the solids be distributed as uniformly as possible to enable efficient screening.

The slurried feed is pumped using a pump **42, 102** onto the first sizing screen **30a, 90a** so that the slurry will flow through the first screen as the first screen removes a first portion of material **50**. For embodiments where the sizing screens **30, 90** are in series (not shown), the slurry is pumped onto the second sizing screen **30b, 90b** so that the slurry will flow through the second screen as the second screen removes a second portion of material **54** and so forth. According to another embodiment, as illustrated in Figures 2 and 3, the sizing screens **30, 90** preferably comprise a screen deck **32, 92** so that the slurry will flow through each screen in succession due to gravity.

As discussed above, the number and sizing of the screens **30, 90** can vary depending upon the specifications of the portions to be beneficiated from the slag. In one embodiment, the screen deck **32, 92** includes a first sizing screen **30a, 90a** and a second sizing screen **30b, 90b** wherein the first sizing screen is a .5 inch (12.7 mm) screen and the second sizing screen is a 20 mesh (841 μm) screen. The first sizing screen **30a, 90a** is structured to remove a first portion of material **50** from the slurry, which comprises oversize extraneous material, so that the remaining slag product within the slurry has a uniform size distribution. The oversize material or first portion of material **50** can be discarded or crushed and added back to the plant feed **70, 170**, as illustrated in Figures 2 and 3. The second sizing screen **30b, 90b** preferably is structured to remove the size fractions with lower carbon content.

Spray bars or nozzles **35, 95** can be used to direct a fluid, such as a gas or liquid, onto one or more of the sizing screens **30, 90** to facilitate particles having a size less than the size of the sizing screens washing through the screens. For example, in one

embodiment, the spray bars or nozzles **35**, **95** direct water onto the first and/or second screens **30a**, **90a** and **30b**, **90b**. Similarly, a vibrator **33**, **93** can be used with the first and/or second screens **30a**, **90a** and **30b**, **90b** to facilitate particles having a size less than the size of the sizing screens washing through the screens.

The first portion of material **50** removed by the first screen **30a**, **90a** will generally have a size equal to or exceeding the sizing of the first screen and the second portion of material **54** removed by the second screen **30b**, **90b** will generally have a size less than the sizing of the first screen and equal to or greater than the sizing of the second screen. For example, where the first sizing screen **30a**, **90a** is a .5 inch (12.7 mm) screen and the second sizing screen **30b**, **90b** is a 20 mesh (841 μm) screen the first portion of material **50** will have a particle size equal to or exceeding about .5 inches and the second portion of material **54** will have a particle size less than about .5 inches and equal to or exceeding about 841 μm. According to this embodiment, the second portion of material **54** will advantageously contain less than approximately 5% carbon and, more preferably, less than approximately 1% carbon.

According to one embodiment of the present invention, as illustrated in Figure 2, after the sizing screens **30** the slurry is pumped using pump **52** into a centrifuge **34**. The centrifuge **34** serves the dual purpose of dewatering the remaining solids while effectively classifying out a third portion of material **56**. As with the sizing screens **30**, the sizing of the specifications of the centrifuge **34** can vary depending upon the specifications of the portion to be beneficiated from the slag. In one embodiment, the centrifuge **34** is structured to separate a third portion of material **56** having a particle size less than the size of the smallest sizing screen **30** and greater than or equal to about 45 μm. For example, if the sizing of the smallest sizing screen **30** is about 20 mesh (0.841 mm), the carbon enriched particles that generally range in size from less than about 840 μm to greater than about 75 μm will be contained and dewatered by the centrifuge **34**. The third portion of material **56** preferably has a higher carbon content than the second portion of material **54**.

As illustrated in Figure 2, the slurry rejected by the centrifuge **34** can be thickened in a static thickener **36** using anionic flocculants and pH modifiers to remove a fourth

portion of material **58** from the slurry. The flocculant provides an adequate settling rate of the flocculated solids, such as about 6 inches to 12 inches per minute. The pH modifiers maintain acceptable water clarity. The fourth portion of material **58** is then pumped from the thickener **36** using pump **66** and dewatered on a belt filter press **38** to produce a "fines" product. The fourth portion of material **58** will generally have a particle size less than the smallest particle size to be removed by the centrifuge **34**. In one embodiment, the fourth portion of material **58** will include particles with a size less than about 45 μm. The fourth portion of material **58** or fines product can be used as a fuel product, for example, fed back into the gasifier **12**, or used as an adsorbent carbon.

According to another embodiment of the present invention, as illustrated in Figure 3, after the sizing screens **90** the slurry is pumped using pump **112** into a hydrocyclone **91**. The hydrocyclone **91** serves the purpose of removing or classifying out a third portion of material **156**. As with the sizing screens **90**, the sizing of the hydrocyclone **91** can vary depending upon the specifications of the portion to be beneficiated from the slag. In one embodiment, the hydrocyclone **91** is structured to remove a third portion of material **156** having a particle size less than the size of the smallest sizing screen **90** and greater than about 75 μm. Accordingly, if the sizing of the smallest sizing screen **90** is about 20 mesh (0.841 mm), the third portion of material **156** will have a particle size of less than about 20 mesh or about 840 μm and greater than about 75 μm. Advantageously, because the carbon enriched particles from the slag by-product generally range in size from less than about 840 μm to greater than about 75 μm, these particles are concentrated within the third portion of the material **156** according to the embodiment illustrated in Figure 3. The third portion of material **156** preferably has a higher carbon content than the second portion of material **54**. The third portion of material **156** can be pumped to the centrifuge **94** for dewatering using pump **132** or via gravity feed. The third portion of material **156** can be used as a fuel product, for example, fed back into the gasifier **12**, or as an adsorbent carbon.

As illustrated in Figure 3, the overflow from the hydrocyclone **91** can be pumped to the thickener **96** using pump **122**. Similarly, the slurry rejected by the centrifuge **94** can be pumped to the thickener **96** using pump **142**. As discussed above, the thickener **96**

can include anionic flocculants to settle a fourth portion of material **158** from the slurry and pH modifiers to clarify the water. The flocculants provide an adequate settling rate of the flocculated solids, such as about 6 inches to 12 inches per minute. The pH modifiers maintain acceptable water clarity. The fourth portion of material **158** is then pumped from the thickener **96** using pump **144** and dewatered on a belt filter press **98** to produce a "fines" product. In one embodiment, the fourth portion of material **158** will include particles with a particle size less than about 75 μm. The fourth portion of material **158** or fines product can be used as a fuel product, for example, fed back into the gasifier **12**, or used as an adsorbent carbon.

The principal difference between the embodiments illustrated in Figures 2 and 3 involves the carbon content of the third portion of material **56, 156**. More specifically, the third portion of material **56**, according to the embodiment of the invention illustrated in Figure 2, will have a lower carbon content than the third portion of material **156**, according to the embodiment of the invention illustrated in Figure 3. Accordingly, for applications where it is more important to have a higher carbon content or Btu value for the third portion of material, the embodiment illustrated in Figure 3 would be more preferable. Alternatively, for applications where it is more important to utilize greater quantities of the slag by-product, the embodiment illustrated in Figure 2 would be more preferable.

As illustrated in Figures 2 and 3, the water from the thickener **36, 96** and belt filter press **38, 98** can be pumped using pumps **80, 180** and **90, 190**, respectively, back to the blunger **38, 88** for mixing with the slag to form a slurry, used in connection with sprayers **35, 95**, used in connection with sprayers for the belt press (not shown), and/or used for the blowdown return.

The size analysis of a composite feed sample from the plant feed **70, 170** according to one embodiment of the present invention are illustrated in Figure 4. Figure 5 shows a condensed size distribution, according to one embodiment of the present invention, once oversize material (*i.e.*, the first portion of material **50**) is removed and selected size fractions (*i.e.*, the second portion of material **54**, the third portion of material **156** and the fourth portion of material **158**) are combined. These results show that the three size

fractions each contain approximately 1/3 of the feed solids. The -4+20 mesh fraction (the second portion of material **54**) contains only 1.8% carbon loss on ignition ("LOI"), while the -20+80 mesh fraction (the third portion of material **156**) contains 63% carbon LOI. The differences in the grade of these two size fractions illustrates the importance of effective classification since carbon is undesirable in the second portion of material **54** and slag is undesirable in the third portion of material **156**. Efficient classification ensures that the grade specifications for both products are maintained. For purposes of example only and not limitation, the size analyses of a second portion of material **54**, a third portion of material **56, 156**, and a fourth portion of material **58, 156**, according to other embodiments of the invention, are illustrated in Figures 6, 7 and 8, respectively.

According to one embodiment of the present invention, as illustrated in Figure 9, the method includes mixing the slag with water to form a slurry. See Box **200**. The mixing step can include agitating the slag to break up any agglomerated particles. See Box **202**. The slurry is screened through a first screen to remove a first portion of material and then screened through a second screen to remove a second portion of material. See Box **204**. A fluid can be sprayed onto one or both of the first and second screens concurrently with the corresponding first and second screening steps to facilitate the passage of material through the screens. See Box **206**. The first and/or second screens can also be vibrated concurrently with the corresponding first and second screening steps to facilitate the passage of material through the screens. See Box **208**. In one embodiment, the second portion of material has a carbon content less than about 5% and, more preferably, a carbon content less than about 1%. See Box **210**. Although the size of the particles in the first and second portions can vary, in one embodiment the first portion of material has a particle size exceeding approximately .5 inches. See Box **212**. In another embodiment, the second portion of material has a particle size of between approximately .5 inches and approximately 840 μm. See Box **214**.

The method further includes screening the slurry subsequent to the second screening step through a centrifuge to remove a third portion of material. See Box **216**. The third portion of material preferably has a higher carbon content than the second portion of material. See Box **218**. The size of the particles in the third portion can vary.

In one embodiment, the third portion of material has a particle size between approximately 840 μm and approximately 45 μm. See Box **220**. The third portion of material can be used as a fuel product or adsorbent carbon. In still another embodiment, the slurry is thickened subsequent to the third screening step using an anionic flocculant such as polyacrylamide or acrylamide copolymers to thereby remove a fourth portion of material from the slurry. See Box **222**. If desired, a pH modifier such as sodium hydroxide or ammonium hydroxide can be used to clarify the water. See Box **224**. The fourth portion of material can thereafter be processed using a belt filtering press. See Box **226**. In one embodiment, the fourth portion of material has a particle size of less than approximately 45 μm. The processed fourth portion of material can be used as a fuel product.

According to yet another embodiment of the present invention, as illustrated in Figure 10, the method includes screening the slurry subsequent to the second screening step using a hydrocyclone to remove a third portion of material. See Box **228**. The third portion of material has a higher carbon content than the second portion of material. See Box **230**. The size of the particles in the third portion can vary. In one embodiment, the third portion of material has a particle size of between approximately 840 μm to approximately 75 μm. See Box **232**. The third portion of material or "underflow" from the hydrocyclone preferably is dewatered using a centrifuge. See Box **234**. The third portion of material can be used as an adsorbent carbon or a fuel product. Subsequent to the third screening step, the slurry can be further processed by thickening the slurry using an anionic flocculant such as polyacrylamide or acrylamide copolymers to thereby remove a fourth portion of material from the slurry. See Box **236**. If desired, a pH modifier such as sodium hydroxide or ammonium hydroxide can be used to clarify the water. See Box **238**. Thereafter, the fourth portion of material can be processed using a belt filtering press. See Box **240**. In one embodiment, the fourth portion of material has a particle size of less than approximately 75 μm. The fourth portion of material can be used as a fuel product.

Accordingly, there has been provided methods and apparatus to beneficiate the slag by-product from gasification economically. The methods and apparatus enable not

only the separation of the slag by-products into useful components, but also the separation of the by-products into useful components with acceptable quality and sizing for specific end use markets. The coarse slag by-product, or first and second portions of the material, can be used for many applications, including abrasive media (*i.e.*, sand blasting grit), polishing media, roofing granules, cement kiln feed, athletic track surfaces, landscaping, and road surface coatings. In addition, the coarse slag by-product can also be milled and used as a pozzolanic cement additive to improve the properties of concrete. The finer slag by-product, or third and fourth portions of the material, can be utilized as a supplemental pulverized coal combustion fuel and has shown excellent potential as both an adsorbent and as a precursor for activated carbon.

Many modifications and other embodiments of the inventions set forth herein will come to mind to one skilled in the art to which these inventions pertain having the benefit of the teachings presented in the foregoing descriptions and the associated drawings. Therefore, it is to be understood that the inventions are not to be limited to the specific embodiments disclosed and that modifications and other embodiments are intended to be included within the scope of the appended claims. Although specific terms are employed herein, they are used in a generic and descriptive sense only and not for purposes of limitation.